

Selective Nonoperative Management of Penetrating Torso Injury From Combat Fragmentation Wounds

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Background: Historically, military surgical doctrine has mandated exploratory laparotomy for all penetrating fragmentation wounds. We hypothesized that stable patients with abdominal fragmentation injuries whose computerized tomography (CT) scans for intraperitoneal or retroperitoneal penetration disclosed nothing abnormal, can be safely observed without therapeutic laparotomy.

Methods: We retrospectively studied all hemodynamically stable patients with penetrating fragmentation wounds to the back, flank, lower chest, abdomen, and pelvis evaluated by abdominal physical examination (PE), CT, or ultrasound treated during a 6-month period at one combat support hospital. Sensitivity, specificity, and positive and negative predictive values were calculated comparing

each positive test to laparotomy and each negative test to successful nonoperative management.

Results: One hundred forty-five patients met study criteria. Based on CT scans, 85 (59%) patients were managed nonoperatively; 60 (41%) underwent laparotomy. Forty-five of 60 (75%) of laparotomies were therapeutic. CT scan for intraperitoneal or retroperitoneal penetration that disclosed nothing abnormal was 99% predictive of successful nonoperative management. In detecting intra-abdominal injury requiring laparotomy, sensitivity for each method was 30.2% (PE), 11.7% (ultrasound), and 97.8% (CT) ($p < 0.05$). Specificity was 94.8% (PE), 100% (ultrasound), and 84.8% (CT). The areas under the receiver operating characteristic (ROC) curves were 0.565 (PE), 0.543 (ultra-

sound), and 0.929 (CT) ($p < 0.0001$). All patients with a positive ultrasound ($n = 4$) underwent therapeutic laparotomy.

Conclusion: PE alone was unreliable in stable patients with abdominal fragmentation injuries. The clinical value of ultrasound results was limited, likely because the majority of these stable patients did not have injuries associated with the large accumulation of peritoneal fluid. CT scan safely and effectively analyzed nonoperative management of penetrating abdominal fragmentation injuries and should be the diagnostic study of choice in all stable patients without peritonitis with abdominal, flank, back, or pelvic combat fragmentation wounds.

Key Words: Combat wounds, Abdominal trauma, Explosion, Computed tomography, Ultrasound.

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Penetrating fragmentation injury to the torso in armed conflict represents a unique wounding pattern rarely seen in civilian trauma. The projectiles range widely in size and velocity. The mechanism of delivery of the projectiles also has

the confounding variable of primary blast injury. Historically, the presence of these wounds on the abdomen, flank, back, or buttocks mandated exploratory laparotomy to rule out intra-abdominal injury. A policy of routine exploration of all penetrating abdominal injuries was introduced in 1915 as a result of the high mortality associated with nonoperative management of these injuries early in World War I.¹ This policy of mandatory exploration of penetrating abdominal wounds, particularly gunshot wounds (GSWs), remained largely unchallenged until the 1990s, when civilian authors reported successful use of selective nonoperative management of abdominal GSWs.^{1–3} However, no series documenting the use of selective nonoperative management of penetrating abdominal wounds caused by explosive or fragmentation munitions has been published, and the mandate to operatively explore all of these patients has remained unchanged since World War I.⁴ The Emergency War Surgery manual (2004) clearly outlines the paradigm of care: “Penetrating injuries below the nipples, above the symphysis pubis, and between the posterior axillary lines must be treated as injuries to the abdomen and mandate exploratory laparotomy.”⁵

Mandatory surgical exploration has, in part, been driven by the need to evacuate casualties out of a theater of combat and the consequent inability of surgeons to continuously re-evaluate casualties who are nonoperatively managed. This paradigm of care likely results in a very low rate of missed injuries and

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essentially no delay in diagnosis. It also undoubtedly results in a substantial rate of nontherapeutic operations, which in civilian series of penetrating abdominal trauma ranges from 3.2% to 37%.^{6–10} These studies show that nontherapeutic laparotomy increases both early and late morbidity,^{6–10} as well as the length of hospital stay and cost.^{3,11}

In combat theaters, the employment of adjuncts to the physical examination (PE) of the abdominal fragmentation injury patient was the natural application of strategies learned by military physicians in US trauma centers. The use of this “technology-driven triage of abdominal trauma” was driven by one simple fact: that performing laparotomy on every casualty with penetrating fragment wounds to the abdomen, flank, back, or buttock would result in unnecessary use of operating room space, time, personnel, and equipment. This unnecessary use of resources could delay the treatment of casualties that need rapid surgical interventions. Additionally, this old paradigm of care would also result in a higher nontherapeutic laparotomy rate and its associated consequences. At the same time, the military surgeon is faced with mass casualty situations and varying evacuation times, which preclude close observation of patients. These two conflicting needs—the need to maximize the use of limited operating room assets, and the need to not miss injuries or delay diagnoses—lend merit to the idea of applying the civilian experience with selective nonoperative management of penetrating wounds—using advanced, rapid imaging technology—to the unique patterns of wounding caused by fragmentation munitions. We hypothesized that stable patients with torso fragmentation injuries, whose computerized tomography (CT) scans for intraperitoneal or retroperitoneal penetration disclosed nothing abnormal, can be safely observed without therapeutic laparotomy.

METHODS

We performed a retrospective study on all trauma patients triaged to the combat support hospital (CSH), the 31st CSH, in Baghdad, Iraq between July 2004 and January 2005. The 31st CSH in Baghdad was the most sophisticated military hospital in the country in support of Operation Iraqi Freedom at the time of this study. Although an Army CSH has most diagnostic modalities available to a US Level I trauma center, it does lack the capabilities of magnetic resonance imaging, angiography suite, and cardiopulmonary bypass. This study was approved by the Brooke Army Medical Center Institutional Review Board (IRB H-05-012). Inclusion criteria were as follows: (1) patients with penetrating mechanism secondary to fragmentation with injuries to the back, flank, lower chest, abdomen, and pelvis; (2) hemodynamic stability (heart rate <120 and systolic blood pressure >90 mm Hg, sustained during the course of emergency room time without requiring repeated fluid boluses); (3) documented PE, focused assessment with sonography for trauma (FAST) examination, and CT scan. Patients included Operation Iraqi Freedom coalition forces and Iraqi nationals.

Patients with obvious abdominal injuries requiring operation (e.g., evisceration) or with hemodynamic instability were recorded but excluded from analysis. Fragmentation wounds resulted from stationary or vehicle-borne improvised explosive devices, rocket-propelled grenades, mortars, hand grenades, or fragmented indirect bullet injuries. This last category of mechanism was presumed to result from multiple high-velocity rounds striking buildings or vehicles containing occupants. The casualties would frequently give a history of being in a vehicle or building struck by multiple rounds, and their resultant injury patterns were presumed to be from fragmentation of the rounds and surrounding structures. These wound patterns were often clinically indistinguishable from those patients whose injuries resulted from fragmentation munitions.

The on call trauma surgeons were responsible for performing the physical examinations and ultrasound examinations. Stable patients routinely received an emergency room PE, a FAST examination, and a subsequent standard single contrast CT scan to evaluate the abdomen after fragmentation wounds. Oral contrast was used rarely and at the discretion of the attending surgeon, usually in the setting of a possible injury to the upper gastrointestinal tract. Both FAST examination and CT scan have been used as triage tools in civilian trauma settings,^{12,13} and they were routinely employed at the 31st CSH as secondary triage tools. A PE was considered positive if the surgeon documented peritonitis or peritoneal signs on the chart. All ultrasound operators had taken an American College of Surgeons-approved introductory course and initial proctoring. Patients were evaluated by ultrasound using a Sonosite 180 (Sonosite, Inc. Bothell, WA) using a 3.5-MHz sector transducer.

Routine trauma ultrasounds consisted of pericardial views, transverse and longitudinal images of the right upper quadrant (right subphrenic and subhepatic spaces), left upper quadrant space (perisplenic and subphrenic), and the pelvis. Often the urinary bladder was distended with sterile normal saline to enhance the visualization of the pelvis. All ultrasound examinations were considered positive if any intraperitoneal fluid was identified and negative if no fluid was identified.

The staff surgeons in conjunction with the staff radiologists evaluated all CT scans. Patients were evaluated by CT with an 8-slice Siemens Somatom, plus 4 (Stuttgart, Germany). All CT scans were considered positive if fragments were identified inside the peritoneal cavity, retroperitoneal hematoma, free air, free fluid, solid organ injury, contrast leak or blush, or if the projectile traversed the rectum. Because US and coalition casualties frequently would have other injuries which required evacuation to higher echelons of care, and therefore could not be observed for much more than 24 hours, the majority of patients with a CT scan which showed peritoneal penetration by fragments underwent exploratory laparotomy. A small number of patients with CT scans that revealed peritoneal or retroperitoneal penetration by fragments were selectively observed. The decision to

observe these patients was based on the assessment that the number and location of the external wounds and the fragment and fragment pathway locations on the CT scan did not appear (prospectively) to have caused significant injuries. To simplify analysis, this group was included with the CT scan group that disclosed nothing abnormal, but was labeled “CT scans with intraperitoneal findings that did not indicate laparotomy”. CT scan findings in these groups included isolated fragment wounds to the liver without significant free fluid, hematoma, or contrast blush, and isolated fragments in the peritoneum or retroperitoneum whose wound paths could be traced from the external wound and were not in proximity to any major organs or structures (e.g., fragment in the psoas muscle from a posterior wound).

All physical examinations, FAST results, and CT results were compared with operative or observational findings. A laparotomy was considered therapeutic if any therapeutic surgical intervention was performed. A laparotomy was considered nontherapeutic when no surgical correction of injuries was required.

Follow-up was obtained until the point of discharge from the 31st CSH for all Iraqi and foreign national patients. Follow-up for US casualties evacuated out of theater was obtained by data search through the Joint Theater Trauma Registry (JTTR) and in some cases by telephone or email follow-up at evacuation (Level IV and V) hospitals such as Landstuhl Regional Medical Center, Walter Reed Army Medical Center.

Statistical Analysis

ROC curves were generated to compare the accuracies of PE, ultrasound, and CT. Significance was determined with alpha set at $p < 0.05$.

RESULTS

During the 6-month study period, a total of 1,645 total trauma patients were admitted and evaluated at the 31st CSH. During this time, 274 patients were evaluated for abdominal injuries. One hundred twenty-nine patients presented with obvious signs requiring laparotomy (e.g., penetrating wounds with evisceration, positive FAST with hypotension, or peritoneal signs with hypotension), or underwent exploratory laparotomy in conjunction with the treatment of other injuries requiring emergent general anesthesia and operation. Of these patients, 117 (91%) underwent therapeutic laparotomy. One hundred forty-five patients were deemed hemodynamically stable with penetrating abdominal, flank, pelvic, or back wounds and therefore met study criteria. Demographics for these groups are found in Table 1. Arrival mean systolic blood pressure, heart rate, temperature (°F), hematocrit, pH, and base deficit are shown in Table 2. Mechanisms of injury included rocket-propelled grenades, grenades, improvised explosive devices, mortars, rockets, and bullet fragmentations.

Of our study group, 139 (96%) patients had PE findings documented, 114 (79%) patients had FAST results docu-

Table 1 Demographics and Wounding Mechanism

Total (N = 145)	N	%
Male (N)	141	97.2
Female (N)	4	2.8
Age (average, yr)*	28	
US/coalition	68	47
Iraqi national	77	53

* Age standard deviation: ± 9 ; and range: 12–70 years.

Table 2 Admission Physiologic Parameters

Physiologic Parameter	Mean SD
Systolic blood pressure	129 \pm 22.5
Heart rate	95 \pm 19
Temperature	98.1 \pm 1.5
Hematocrit	38 \pm 7.17
pH	7.33 \pm 0.08
Base deficit	3 \pm 3.1

mented, and 145 (100%) patients had CT scan results documented. The sensitivity, specificity, positive predictive value, negative predictive value, and the area under the ROC curves of PE, ultrasound, and CT examinations are shown in Table 3. The odds ratio and test accuracy for PE and computed tomography are also displayed.

Operatively Managed Study Patients

Of the total 145 patients in the study database, 60 (60 of 145, 41%) underwent an exploratory laparotomy. Of these patients, 45 of 60 (75%) were therapeutic laparotomies. Specific injuries and number of positive physical examinations, FAST examinations, and CT scans for each type of injury are listed in Table 4. Of the 15 of 60 (25%) nontherapeutic laparotomies, 4 of 15 (27%) had no evidence of peritoneal penetration even though the CT scan had been interpreted as positive for peritoneal penetration of fragments (false-positive CT scan). The remaining 11 patients actually had findings of peritoneal penetration in the abdomen which did not require any therapeutic surgical intervention. Examples of these findings include non-expanding retroperitoneal hematoma (e.g., psoas muscle), fragments in the abdomen that did not injure any organs, and small amounts of clotted blood on the omentum. In one case calcified seed husks from the patient's diet (which were interpreted on the CT scan as fragments in the small bowel) were identified during evaluation of the small bowel. In another case, free air, but no metallic fragments, was seen in the abdomen, and exploration revealed nonmetallic fragments (black plastic, possibly pieces of body armor) but no organs injured.

Nonoperatively Managed Study Patients

Eighty-five (59%) patients were selectively managed nonoperatively based on CT scan findings and clinical appearance. The mean and median follow-up for this group of patients was 7.0 days \pm 0.6 (SD) and 6 days, respectively,

Table 3 Comparison of Accuracies of Diagnostic Tests

	PE	US	CT
Sensitivity (%)	30.2	11.7	97.8*
Specificity (%)	94.8	100	84.8
Positive predictive value (%)	72.2	100	75
Negative predictive value (%)	75.4	73.2	98.8*
Odds ratio	7.97	—	242 [†]
Accuracy (%)	75	—	89
Area under ROC curve	0.565	0.543	0.929*

* $p < 0.05$.[†] 99% confidence interval (16.89–3759.85).

US indicates ultrasound; CT, computerized tomography; PE, physical exam; PPV, positive predictive value; NPV, negative predictive value.

Table 4 Specific Injuries

Organ Injured	N	PE Positive	FAST Positive	CT Scan Positive
Colon	20	6	1	19
Small bowel	14	5	1	13
Diaphragm	10	1	0	10
Spleen	7	1	1	6
Kidney/adrenal	7	1	0	6
Liver	6	2	2	6
Rectum	3	1	0	3
Pancreas	3	1	0	3
Urinary bladder	2	2	0	2
Major vascular/vein	2	1	1	2
Heart	2	0	0	2
Duodenum	1	1	No result recorded	1

77 injuries in 45 patients who underwent therapeutic laparotomies.

with a range of 1 day to 31 days. Follow-up of the US casualties was obtained via query of the JTTR and telephonic or email follow-up with evacuation hospitals (Landstuhl Regional Medical Center, Walter Reed Army Medical Center, or Brooke Army Medical Center). Follow-up data on Iraqi national patients was kept in the 31st CSH database.

Seventy-five of these patients had CT scans, for fragments inside the peritoneal cavity, retroperitoneal hematoma, free air, significant free fluid, solid organ injury, contrast leak or blush, or a projectile that traversed the rectum, which disclosed nothing abnormal. None of these patients required subsequent abdominal exploration. Ten patients with CT scan findings that revealed penetration of the peritoneum or retroperitoneum were initially managed nonoperatively. In two of these cases, additional adjuncts (rigid proctoscopy in 1 case, repeat CT scan with rectal contrast 12 hours later) were used in the evaluation. Of these 10 patients, 9 of 10 (90%) patients recovered without sequelae. Eight of the 10 observed patients (80%) were Iraqi nationals and did not require evacuation, so observation for several days at the CSH was feasible. Six of these Iraqi nationals had peritoneal, retroperitoneal, or intrapelvic fragments, and fragment trajectories which were judged not to have injured any organs. These findings were combined with benign clinical examinations and, in the case of

the intrapelvic fragments, rigid proctoscopy to conclude that a period of observation rather than laparotomy was warranted. The remaining two of these eight Iraqi nationals had fragment wounds to the right upper quadrant and penetration of the liver. One recovered without sequelae. The other developed a biliary-pleural-bronchial-cutaneous fistula 11 days after admission, which required laparotomy, thoracotomy, and eventually evacuation out of Iraq to a facility where endoscopic retrograde cholangio-pancreatography was available. This patient eventually recovered. Review of this case concluded that the patient would likely have benefited from earlier laparotomy.

The two US patients in this nonoperatively managed subset were casualties who were stable and did not have concomitant injuries requiring immediate evacuation; both of these patients had fragment wounds to the back with penetration of the retroperitoneum but no associated hematoma, intraperitoneal fluid, or free air. These two patients were observed for 1.5 days at the CSH before evacuation without the development of adverse sequelae. Subsequent JTTR query demonstrated that neither patient required surgical or other interventions. The study flow diagram and results for all patients are shown schematically in Figure 1.

DISCUSSION

The evaluation of the abdomen, back, flank, and pelvis is of paramount importance to the combat general surgeon, faced with the limited resources often seen in a mass casualty situation. Because of the varying mass and velocities of the multiple projectiles explosive weapons produce, perhaps the only civilian trauma equivalents are industrial accidents or explosions. Casualties often have fragment injuries throughout the body (Fig. 2). These wounding mechanisms currently represent the most common cause of injury in Iraq and Afghanistan. Observation and serial examinations, now widely used for stab wounds, flank wounds, and back wounds, are not an option in many patients because of mass casualty events, varying transport times for evacuation, and concomitant neurologic injuries. Precious operating room time should be limited to those who need a therapeutic laparotomy and any modality that can help triage these patients will save lives.

The civilian trauma literature has shown that in stable patients without peritonitis, nonoperative management has been used successfully in penetrating injury to the back, flank, and anterior abdomen caused by GSW and stab wounds.^{2,3,11,14–16} Even when peritoneal or retroperitoneal penetration of bullets and organ damage is revealed on imaging, studies have demonstrated that injured organs (e.g., liver, kidney) and injury patterns can be safely managed nonoperatively.^{17–21} This approach of selective nonoperative management of both blunt and penetrating abdominal trauma has resulted in an acceptably low incidence of missed injuries, delayed diagnosis, and deaths.^{1,22} Demetriades and Velmahos, in their review article on the “emerging era of nonoperative management”, emphasize that this strategy re-

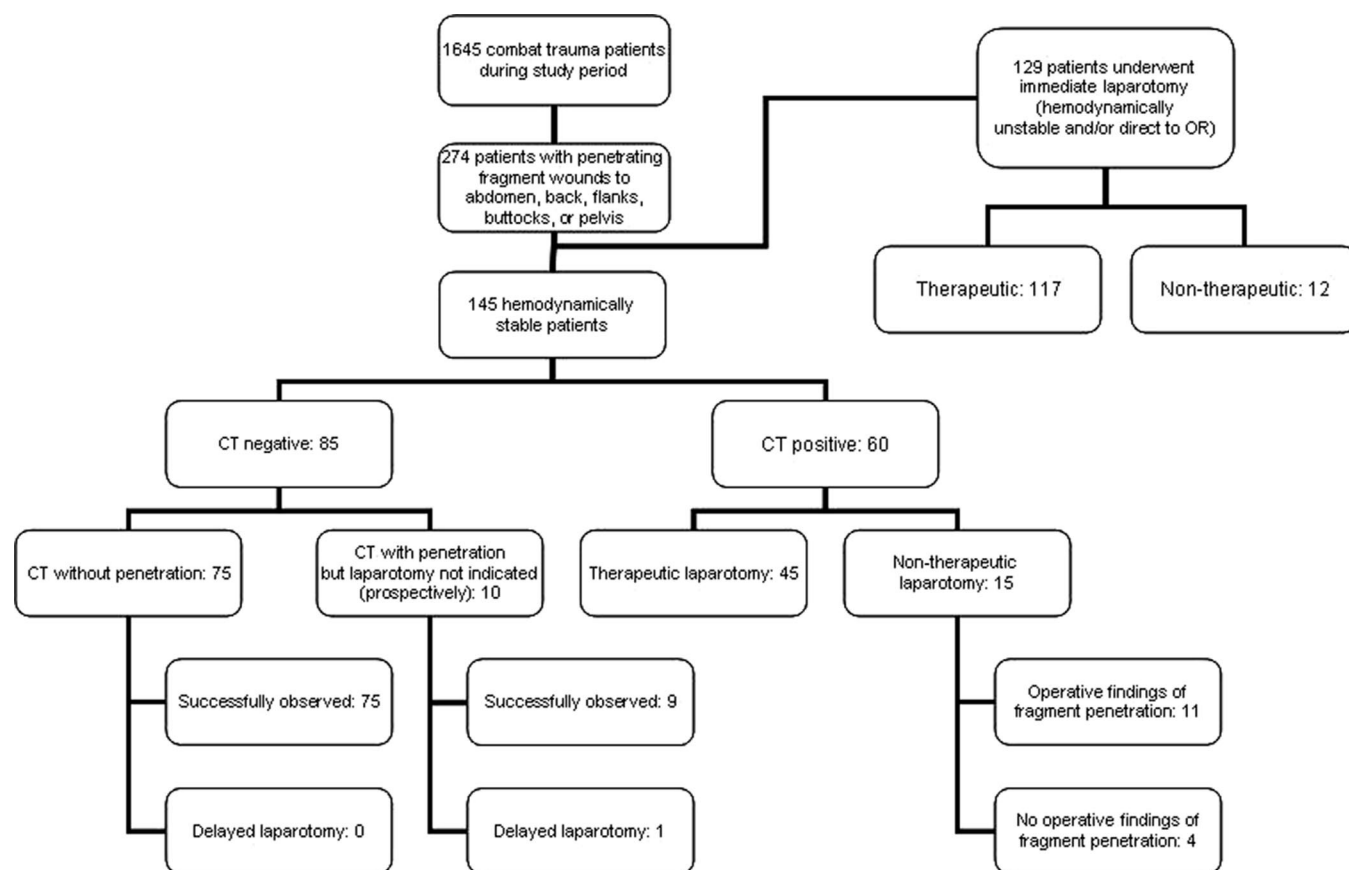


Fig. 1. Study flow diagram and schematic representation of all patients.



Fig. 2. Scout film from CT scan showing wide distribution of penetrating fragments from explosive munition.

quires a combination of appropriately selected investigations such as CT combined with careful PE for success.¹

Although initial PE is a valuable evaluation and triage tool, its unreliability in trauma scenarios has been well documented. Specifically, young patients who have had short prehospital times may not demonstrate hemodynamic instability, even in the presence of substantial cavitory hemorrhage.¹ The fragmentation

injury patterns seen commonly in the recent operations in Iraq often feature multiple penetrating wounds resulting in severe abdominal wall pain on palpation, making PE less reliable (Fig. 3). Patients frequently present with other injuries, including traumatic brain or spinal cord injuries, which can also make clinical examination of the abdomen unreliable. Hence, deployed military surgical facilities employ modalities commonly used in civilian trauma centers as an adjunctive assessment for intra-abdominal injuries. These modalities include FAST, diagnostic peritoneal lavage (DPL), and CT. Each of these modalities has reported strengths and weaknesses, hence it has been suggested that they be used in a complementary fashion.^{1,23–26}

In our study, PE did not reveal peritonitis in many patients who subsequently underwent a therapeutic laparotomy, with a PE sensitivity of only 30%. This could be a reflection of the lack of time necessary for accumulation of intraperitoneal succus, fragments that penetrated through the back or flanks and injured retroperitoneal structures, significant masking abdominal wall pain, or concomitant neurologic injury. It should be noted that 129 patients underwent laparotomy based primarily on PE findings (e.g., peritonitis, evisceration, or hemodynamic instability) or positive FAST examination during the study period, but these were excluded from analysis as the primary focus of our study was the evaluation of the stable patients with fragmenta-



Fig. 3. Casualty with burns and multiple fragment wounds of varying size and depth, secondary to an explosive munition. Note near “head to toe” distribution. (Photo courtesy of LTC Tommy A. Brown, MD, FACS).

tion wounds to the abdomen. Since 91% of the laparotomies in this subset of unstable patients were therapeutic, inclusion of these patients would make the sensitivity of PE and FAST much higher.

The low sensitivity of FAST to detect peritoneal penetration and intra-abdominal injury in our study subset was most likely because of the fact that the fragmentation injuries often resulted in small or large bowel injuries (48% of all patients undergoing laparotomy from 31st CSH—75% of patients in this cohort). It is widely known that hollow viscus injuries often do not result in significant intraperitoneal fluid. Stassen et al. revealed that initial admission ultrasound had a prohibitively high false negative rate to be of any clinical use in diagnosing small bowel injury after blunt trauma.²⁷ Our data corroborates that ultrasound cannot be used to rule out a hollow viscus injury in penetrating fragmentation wounds. Our practice was to use FAST as a secondary triage tool, particularly because we identified patients who suffered both penetrating and blunt abdominal injuries (e.g., casualty’s vehicle hit by explosion or fragmentation, then crashed into wall or other vehicle). FAST was used to identify major intra-abdominal hemorrhage in hemodynamically unstable patients to help sequence interventions. In hemodynamically stable patients, it was used to help prioritize patients for further diagnostic studies, such as CT scan. Hence, FAST provided utility primarily when results were positive, as has been demonstrated in civilian evaluations of FAST.²⁴ We concluded from our study that a negative FAST in a patient with penetrating truncal injuries could not rule out an intra-abdominal injury, and hence these studies would usually be followed with a CT scan.

At the beginning of this study, we were concerned with the unique nature of these wounds and the potential pitfalls of using CT and ultrasound to evaluate for intraperitoneal or

pelvic injuries. These potential pitfalls include missing primary blast injury (injury caused by the blast wave or overpressure^{28,29} and not flying debris or projectiles) and projectiles that completely traverse the peritoneal cavity and lie in an “extraperitoneal” position.³⁰ We found no evidence of either phenomenon in our patients as all injuries were noted to be caused by the projectile or revealed a missile tract. In several cases, casualties arrived with several penetrating wounds on back, flanks, and abdomen, but had no evidence of peritoneal penetration of these fragments on CT scan (Fig. 4). These patients were successfully treated nonoperatively. On the other hand, several patients arrived with a few very small (<5 mm) penetrating wounds to the abdomen and were hemodynamically stable and without abdominal pain or tenderness. CT scan of some of these casualties revealed fragments in the lumen of bowel or other injuries which required operation (Fig. 5). Furthermore, all surgeons involved with these injuries think the CT scan was invaluable as it allowed for extensive focused dissection along the fragment’s intra-abdominal path.

Our nontherapeutic laparotomy rate (25%) for the hemodynamically stable study group reflected the cautious application of a selective nonoperative management strategy to an inherently different and more variable wounding mechanism (than to which it has been applied in civilian settings). When all laparotomies during the study period are included in analysis (as occurs in many studies dealing with this topic), our nontherapeutic laparotomy rate falls to 14%. In a recent collective review of 16 series involving 8111 civilian patients with penetrating abdominal trauma, the incidence of nontherapeutic laparotomy was 20.9%.³¹ Our rate of nontherapeutic laparotomy rate is similar to the rate in this review, but higher than series from centers that regularly practice selective nonoperative management of these injuries.^{3,14,32} We were aggressive

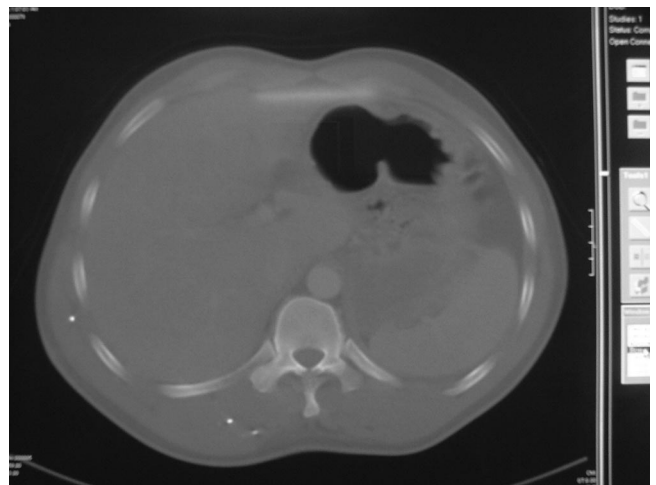


Fig. 4. CT scan of patient who suffered multiple penetrating wounds to back and flank from explosive munition. All fragments were demonstrated to be extraperitoneal on CT scan. Patient was successfully managed nonoperatively.

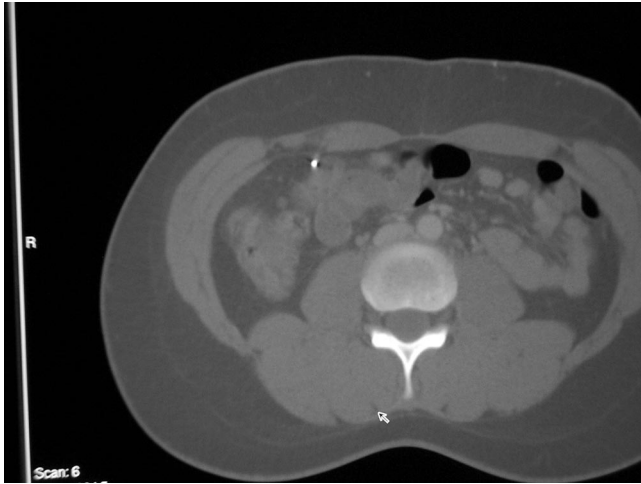


Fig. 5. CT scan of patient who suffered single <5 mm penetrating wound to the right upper quadrant of the abdomen. The patient presented to the CSH hemodynamically stable and without abdominal pain. CT scan demonstrated single fragment in the abdomen, which on exploration had perforated the small bowel.

in exploring those patients who had CT scans which were interpreted as being positive for intraperitoneal or retroperitoneal fragment penetration, particularly when injury to bowel or retroperitoneal structures could not be safely ruled out.

There were multiple reasons, both anecdotal and tactical, justifying this attitude. First, rapid evacuation of US casualties out of theater and the tempo of ongoing operations precluded safe clinical observation of these patients. Second, although we did not see a single case, the true incidence, clinical appearance, and radiologic findings of primary blast injury to intra-abdominal structures has not been well defined and contributed to our lower threshold to explore patients who had explosions as their wounding mechanism. Third, the authors saw a patient early in their experience in Iraq who by CT scan appeared to have fragments which were clearly in the peritoneal cavity but not in the bowel, and were not associated with substantial free air or fluid. This patient was explored and found to have no direct bowel injuries but rather full-thickness burns to small bowel and sigmoid colon related to proximity to the hot fragments (Fig. 6). Fourth, the failure of CT scan to identify nonmetallic fragments, although rare, remained a concern. Hence, patients with penetrating torso wounds and small amounts of free fluid or air in the abdominal cavity but no obvious metallic fragments or exit wounds were often explored because of the possibility of nonmetallic fragments in the abdomen. Fifth, accurate delineation of the trajectory of fragments in patients with multiple fragment puncture wounds was often difficult, and therefore any evidence of peritoneal penetration (free air, free fluid, or intra-abdominal metallic fragments) typically resulted in the surgeon choosing to explore the patient to rule out an injury. Finally, many of these patients had concomitant orthopedic, neurologic, or other system injuries that required relatively

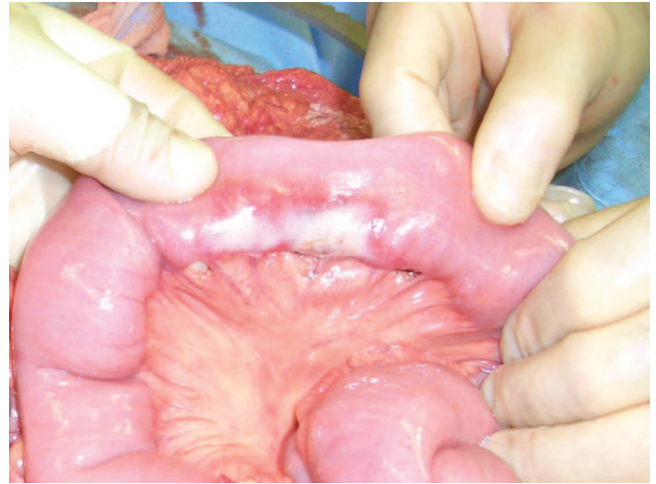


Fig. 6. Intraoperative photo of patient with full-thickness burns to small bowel secondary to hot fragment in the abdomen. (Photo courtesy of LTC Tommy A. Brown, MD, FACS).

prompt evacuation, and hence observation was not an option. This need for evacuation was frequently driven by patient status, but was also at times driven by the current operational tempo, which could be as high as 10 to 30 new trauma admissions per day, or by ward and intensive care unit bed availability. Thus, the authors accepted that a number of nontherapeutic laparotomies would be performed to prevent missed injuries in these challenging circumstances.

Limitations

Identified limitations of this study include its retrospective nature. In some cases, documentation of PE findings was vague or brief, and as a result the PE was only called positive when the physician clearly documented peritonitis. This limitation may help account for the low sensitivity of PE in the study group. In other cases the results of the FAST were not documented, which could similarly skew the evaluation of FAST as a diagnostic modality. These types of limitations are common and often unavoidable when conducting research in a combat theater. As already noted, 129 excluded patients underwent laparotomy based on PE findings (and FAST findings) with a high therapeutic laparotomy rate, indicating that PE and FAST still have a valuable role in the overall approach to combat trauma patients. We also did not frequently use or study the use of DPL as a diagnostic modality in these patients. Because these casualties frequently had other injuries that required evaluation by CT scan (e.g., intracranial or facial injuries), CT scan largely supplanted our use of DPL. In the vast majority of cases the information gained by abdominal CT scan allowed us to make a decision regarding need for operative exploration. Nevertheless, there is the potential for DPL to be employed in cases where peritoneal penetration of fragments is present on CT scan, but the presence of an injury requiring surgical therapy is in question. Eleven of our patients had evidence of peritoneal or retroper-

itoneal penetration on CT scan but underwent nontherapeutic laparotomy. The selective or complementary use of DPL in these circumstances could potentially reduce our nontherapeutic laparotomy rate further.

Several patients had limited follow-up (in a few cases, as little as 1 day) because of transfer to an Iraqi medical facility or evacuation from theater. Delayed presentation of missed injuries could theoretically occur in these patients, and this would be missed in our study. Currently, the JTTR does not contain detailed Level V data, although follow-up was obtained in many of our patients through phone interviews or record reviews. We think these limitations are counter-balanced by the statistically valid results and the robust follow-up data for the majority of our patients, which is the longest overall follow-up of any published study evaluating nonoperative management of penetrating abdominal wounds. We were able to avoid unnecessary laparotomy in more than half of hemodynamically stable patients with penetrating abdominal fragmentation wounds after explosion.

Recommendations

We surmise that the new generation of CT scanners (higher than 8-slice) may afford even better specificity for penetrating abdominal fragmentation injuries. Future studies should be designed to elucidate specific CT injury patterns that can be safely observed, and study the complementary use of other diagnostic modalities such as DPL in reducing nontherapeutic laparotomy rates.

The employment of CT scan in the evaluation of penetrating abdominal fragmentation injuries must be part of a balanced, thoughtful approach to these patients that involves careful PE and the complementary use of FAST and possibly DPL in certain circumstances. This strategy should only be employed in patients who are hemodynamically stable and have no obvious physical findings that would mandate laparotomy (e.g., evisceration).

High quality CT scans should be available at all deployed CSHs (Level III). This diagnostic modality should be available as soon as possible to casualties in all future conflicts. Using this capability decreases nontherapeutic laparotomy and increases efficient use of scarce operative services.

The strategy of selective nonoperative management may be applicable to other fragmentation wound patterns (e.g., penetrating neck injuries) and should be validated with appropriate studies.

CONCLUSIONS

Fragmentation injuries are unique to military conflicts and terrorist bombing attacks. There is no equivalent civilian trauma injury. Based on our data, we concluded that selective nonoperative management of penetrating abdominal fragmentation wounds is safe. There were no unanticipated sequelae of primary blast over-pressure. The practice of selective nonoperative management of these injuries represents a significant change from the traditional military practice of mandatory laparotomy for all

penetrating abdominal wound casualties. Military medical teaching must rapidly adjust to reflect this change. Employment of selective nonoperative management of these injuries avoided laparotomy in more than half (59%) of the stable patients who suffered penetrating abdominal fragmentation wounds. The resulting reduction in nontherapeutic or unnecessary laparotomies potentially reduced hospital stay, short- and long-term sequelae, and hospital costs for these patients. The best evaluation for intraperitoneal penetration and injury by combat fragmentation munitions is newer-generation computed tomography (at least 8-slice).

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DISCUSSION

Dr. Warren C. Dorlac (Landstuhl Regional Medical Center, Landstuhl, Germany): I congratulate Dr Beekley and colleagues on their important presentation. Their findings translate paradigms used in civilian trauma to wartime casualty care, describing a data set that forms the basis for a significant change in coalition casualty care. Fragment wounding even as recently as 1993 with American troops in Somalia mandated abdominal exploration.¹

Whereas the authors discuss the issue of care along a transport continuum, worth emphasizing is the ability (or lack thereof) of other members of the trauma system to view radiographic images. Use of CT as a screening tool for

fragment injuries was an agreeable method rather early on in the current conflict. However, in order for this to work, the films and/or radiologist interpretations must be available to others who may end up caring for the same conservatively managed patient. LRMC is the American receiving facility in Germany for all casualties evacuated out of theater; casualties usually arrive within 24 hours to 72 hours postinjury. During the time of this article's data collection, an in-theater CT scan was often repeated at LRMC unless readable images arrived (via CD) or there was a written report. CT examinations were subsequently repeated after evacuation to stateside medical treatment facilities. What effect these repeated CT scans might have had on renal function or additional transport complications is unknown. Although this problem has now been mostly resolved with electronic documentation, improved imaging, and a Picture Archive and Communication System, it would be interesting to know how many of those in this study underwent repeat imaging. The availability and quality of CT scans has also continued to improve throughout the war. CT scan upgrades have resulted in new 16 slice scanners being deployed to Afghanistan and Iraq and numerous other facilities have CT scanners as well.

Diagnostic peritoneal lavage (DPL) has been utilized at LRMC on a limited basis in this same patient population, mostly for the evaluation of free fluid identified on delayed CT scans. DPL use has diminished as the need for repeating CT scans has also diminished. During a 3-year period at LRMC, only one DPL had >500 WBC after a blast injury with a concern for intra-abdominal free fluid.

Management based on trajectory determination of a single bullet has been described,² but predicting injury based on trajectory is more difficult to accomplish in fragment wounding. The CT scan images shown in this article present one problem: the sheer number of wounds. Other problems stem from different types of fragments (metal, plastic, rock, etc., all with varying radio lucencies), all traveling at different velocities, and the difficulty of linking a given hole to a specific fragment. In penetrating GSWs, one can use the number of wounds and number of bullets seen on radiographs to help determine whether all bullets have been accounted for. This is often not possible in the face of multiple fragment injuries.

During a 3-year experience of receiving these patients while at LRMC, both false negative and false positive studies were encountered. False negative studies that stand out include the following: CT misread by downrange surgeons or radiologists (perigastric and esophageal fragments missed in the face of a mass casualty situation); incorrect trajectory presumptions made of fragments and CT scan of other areas not performed missing injuries in these areas (missed diaphragm, pericardial, myocardial injuries); delayed perforation thought to be secondary to blast injury (colon perforation with surrounding contusion in one case and a small bowel perforation with surrounding contusion in another). This emphasizes the continued validity of serial examinations and evaluations in these patients. False positive studies were more

limited, but included intraluminal/intra-abdominal fragments, which turned out to have originated from swallowed fragments secondary to concurrent oral trauma; localized free fluid around the duodenum, which turned out to be secondary to resuscitation only as no injury was identified.

Questions that I have for Dr. Beekley are: (1) How specifically did you determine which patients met your inclusion criteria? Was a prospectively collected database used? I would have expected more patients to meet the inclusion criteria than the number mentioned (only 274 of 1,645 patients). (2) Use of single or double contrast CT scans was mentioned, but was there any protocol followed for when to utilize one over the other, and if not, has one been developed and followed subsequent to your evaluation of this data? (3) Ultrasound (US) results were 'limited'. How many patients had completed US reports in the charts? Was this used as a triage tool in this group of patients? (4) What was considered significant free fluid in the face of fragments for US and for CT? (5) Would a finding of free fluid on FAST alone warrant a laparotomy or would that patient still proceed to CT (assuming no peritonitis and hemodynamic stability). (6) Has your use been protocolized and if so, how many days of observation are "required" before discharge for the foreign nationals now at the Ibn Sina CSH?

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Dr. Alec C. Beekley (Department of General Surgery, Madigan Army Medical Center, Fort Lewis, WA): I would like to thank Dr. Dorlac for his constructive review of our manuscript. He correctly points out some of the pitfalls in adopting a strategy of selective nonoperative management of penetrating torso injuries in combat casualties, particularly in the setting of a robust and rapid evacuation chain. If anything, his comments lend support to our decision to take a conservative approach with these injuries and our resulting nontherapeutic laparotomy rate, which, as noted, is higher than in centers which routinely practice nonoperative management of penetrating torso injuries.

To answer Dr. Dorlac's specific questions: (1) patients were enrolled by the lead author approximately 2 months

into a 6-month deployment. Data was collected retrospectively for the first 2 months of that deployment by systematic review of abdominal CT scans and corresponding patient charts. Data was collected prospectively for the last 4 months of the deployment, using the inclusion criteria listed in the methods. For the study time period, 274 of 1,675 (17%) had abdominal (torso) injuries. Our numbers compare favorably with JTTR data from October 2001 to November 2005, which revealed that of 3,177 casualties during this period, 8% sustained abdominal injuries, 5% sustained chest injuries, and 2% sustained spine injuries, for a total of 13% (unpublished data, personal communication, Col John B. Holcomb MD, Commander, United States Army Institute of Surgical Research). It should be noted that we did not include isolated chest or neck injuries in our study group. (2) Oral contrast or rectal contrast preps prior to CT scan were used occasionally and at the discretion of the attending surgeon. The standard protocol was a single intravenous contrast prep. Delayed views were occasionally obtained if there was a concern for genitourinary injury, and CT cystography was also occasionally used. A standard single contrast prep for torso CT scans is still in use at the 28th CSH in Baghdad. (3–5) FAST results were available in 114 (79%) patients. The manuscript has been adjusted to reflect this. FAST was used as a triage tool in multiple casualty scenarios, and most patients underwent FAST on arrival as a routine. It is difficult to quantify "significant" free fluid on US or CT scan; that being said, free fluid in more than one quadrant of the abdomen or estimated to be greater than 500 mL was considered significant enough to warrant either laparotomy or observation in the ICU, based on the surgeon's discretion, the patient's other injuries, and the overall operational tempo of the hospital. Patients with positive FAST would still proceed to CT scan if they were hemodynamically stable and did not have peritonitis, as occasionally these patients would have injuries (isolated liver) which could be managed nonoperatively. The presence of a positive FAST would prioritize their CT scan ahead of other stable patients in a multiple casualty scenario. (6) Our results have not yet been incorporated in a clinical practice guideline, as there is a more expansive, ongoing study at the 28th CSH to evaluate the utility of CT scan in determining the need for operation in patients with penetrating neck, chest, abdominal, or periarticular injuries.